INTERACTIVE SIMULATION OF ANTI - AIRCRAFT GUNS COMBAT

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

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to the

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

APRIL, 1987

CERTIFICATE

Certified that this work on 'Interactive Simulation of Anti-Aircraft Guns Combat' by Squadran Leader S.T. Srinivas has been carried out under our supervision and that this has not been submitted elsewhere for a degree.

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my thesis supervisors Prof. V. Sinha and Prof. S.G. Dhande for providing constant help and able guidance during the course of this work.

I would like to thank all the Research Engineers at CAD project who extended their help at time of need. I thank Mr. J.S. Rawat who did a speedy and efficient job of typing this thesis.

Sqn Ldr S.T. Srinivas

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ABSTRACT

Air combat simulators are used by advanced airforces of the world for tactics evaluation and/or training. This work involves the modelling and simulation of anti-aircraft guns, an element of the total air defence network. The simulated combat has been modelled mathematically using war gaming techniques.

It has been implemented in two distinct phases: one an automatic mode to evolve the estimate of the game with given parameters; second, the interactive mode to test the strategy of combat. Software techniques have been used to simulate the actions of a bomber pilot and a gunner. Bill board type representation has been used to represent the progress of combat graphically in automode. In the interactive mode head-up display concepts and radar picture for the gunner has been shown.

The program is implemented on a NORSK DATA 560 CXA computer system using FORTRAN-77 language. For graphics view generation PLOT-10 GKS library routines alongwith the set up commands of TEKTRONIX-4109 colour graphics terminal have been used. The simulation uses discrete event simulation methods.

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CHAPTER 1

INTRODUCTION

1.1 WAR GAMES

War games have been played since very long either as a form of relaxation or an aid in the study of tactics by military commanders. In the present day scenerio they form an important part of the commanders work.

1.1.1 History:

The origin of the modern day wargames can be traced to Prussia in 1811. Baron Von Resswitz and his son Lt. Von Resswitz converted the chess board oriented wargame to that of a sand model. The son popularized the game further by drawing up rules based on actual experience. Later on war games were played using mechanical tinplate soldiers and musket models. Generally these games represented infantry battles and played on a table top terrain with players manoeuvring their forces according with laid down rules to represent real life military action. The progress of the game and the results were computed manually using rules derived from military knowledge.

With the evolution of operations research and developments in digital computers, war games in post war era received the necessary impetus. Use of computers has expanded the field of applicability of 'war games' to whole of military activity, The frantic pace of advancement of military technology, sophisticated weapons, delivery vehicls and various functions have increased the number of variables in a military activity. This complex system naturally has to be modelled using computers rather than pre-war mechanical models.

1.1.2 Purpose:

One or more of the following necessiates the simulation of war games:

i) To test a battle strategy
ii) To ascertain the effectiveness of a weapon system
iii) To train combatents
iv) For entertainment

Simulation of war games is required to be as close to the real life situation as possible. The computer aided war gaming has developed into a complex activity requiring large resources. Governments and large companies support

war gaming projects for military applications/promoting and assessing the potential of their products. War gaming has also been used as an educational and training tool and for scientific analysis of a battle. Analogous to the execution of any big project in modern times it is necessary for a military commander to test his strategy on a simulation model first, before actually executing it. One can predict well in advance the moves and countermoves of commanders of future wars, in various theaters using these wargames.

War games enable a complex system to be analysed and assessed [1]. These can be used to study complicated situations for which it is not possible to set up an analytical model of performance either because the rules covering the decision process involved in the system cannot be formulated mathematically or because the effects of interaction between the component parts of the system are too complicated to be specified precisely in advance. Secondly they allow the introduction of probabilistic and random events. Thirdly one can have a hybrid of the above two elements. Thus physical models (terrain models in war game) can be combined with mathematical models

(assessment rules) and with decision process fed in by human operators. In analytical model of a combat situation, it is necessary to express explicitly in mathematical terms all the effects of terrain on the performance of the system and also, to describe human decision process mathematically. Fourth, the attempt to set up a game automatically draws attention to areas of particular sensitivity. A simulation carried out with visual display provides considerable insight into what are the really important elements of the system studied, and leads to the development of scientific intuition , by helping the mind to picture what goes on.

But it is difficult to apply methods of optimisation. The approach used is one of trial and error, to make successive modifications to the system under study. In purely analytical models optimisation solution can be reached easily. Further to set up and play a game of simulation, requires a considerable amount of time and effort and the availability of considerable resources.

1.2 AIR WAR GAME MODELS

Present day air war operations include the following.

i) Strategic reconnaissance

ii) Strategic bombing

iii) Air superiority

iv) Close air support

v) Interception

vi) Interdiction

vii) Transport support and casuality evacuation

viii) Tactical surveillance and fire control

ix) Electronic surveillance

x) Electronic countermeasures

xi) Air defence

Earlier air warfare models were table top models. Terrain and various installation models were placed on a table. Miniature models of air craft, hung by wires flew above the scenerio. The air craft were moved by wires and stands in horizontal and vertical direction over the combat space governed by specific rules so as to represent actual aircraft parameters. The models were physically manupulated and interactions between weapon/target or weapon/air craft were manually computed according to pre-determined rules. In such simplistic mechanical simulation, a number of factors like pilots skill, accurate positioning

and attitude determination for the air craft could not be incorporated. Still till the advent of computers and use of it in war gaming these simulations provided useful role.

With the advent of multirole air-craft, radars, electronic warfare and numerous sophisticated command and control systems, air war game could not be represented by mechanical models. The present day air war games are the simulation of air war on digital computers. The outputs of the simulation contribute significantly to real-life situations. The air war activities are mathematically modelled to include as many characteristics of the activity as desired. The quality of the representation is limited by what one can afford in terms of cost and time.

1.3 AIR-CRAFT SIMULATORS

The mostly used simulators pertaining to air craft are of two types

i) Landing air craft simulators

ii) Air combat simulators.

The landing air craft simulator simulates the flight of a single landing air craft within the space in vicinity of a landing airstrip. The simulator operates on a circuit

approach of air craft, i.e. from a low level flight point on the approach line down on a landing strip.

An air combat simulator is different from the earlier one. It operates in a much larger combat area and involves more than one single air craft. Besides air craft various elements of combat like anti-aircraft guns (AAG), anti-aircraft missiles (AAM), radars, etc. are also included. To bring out the experience of real combat the specifications of the systems must relate satisfactorily to the real life interaction.

The development of such a system therefore, will be a very large project; in terms of cost, hardware and effort. The present work endeavours to provide the simulation of combat between a bomber aircraft and a battery consisting of AAG. It includes all the essentials required to simulate the combat both in automatic mode and interactive mode.

1.4 USERS VIEW OF SIMULATION

The simulation is intended to be used for the purpose of training and strategy evolvement by a military commander in the AAG combat area. The simulation is developed in two phases

i) Automatic mode

ii) Interactive mode

1.4.1 Automatic Mode:

In this mode the specifications of the combat are given at the start of the simulation. A maximum of five bombers and five guns can take part simultaneously. AAG battery consist of 1 to 5 guns kept close together. We assume the bombers flying at an altitude between 100 m to 1000 m to arrive at 2s intervals. The bomber flies along a straight line over the AAG battery. The speed of a bomber is between 210 m/s to 300 m/s. When a gun fires at a particular aircraft the shell travels at a speed of 1000 m/s. If the shell and its target meet at a distance d from the AAG, the aircraft is destroyed with a probability max(0, 0.3-d/10000). After firing a shot reloading the gun takes finite time. When the aircraft is within the range of dropping the bombs it does so destroying each gun with probability 0.2 independently of what happens to its neighbours. All the guns fire independently. Each gun fires at a leading aircraft which is incoming when it is in range. It again fires when reloading of gun is over. It fires at the nearest outgoing aircraft when there is no incoming aircraft.

1.4.2 Interactive Mode:

In the interactive mode there is only one bomber and a battery of AAG, which are independently controlled. The speed, altitude and release of bombs can be controlled for the bomber. Similarly the firing of gun can be controlled separately. For the aircraft the head-up display concept is used to depict speed, altitude and bombs state. For the guns the position of the aircraft is depicted on a radar screen.

1.5 SIMULATOR CONSTRUCTION

To construct a simulation, the system or process to be simulated is first analysed and purpose of simulation is defined [2]. One specifies the various attributes of the system. These are incorporated in the computer programme. The first step is to build a model for simulation. Models can be classified in many ways. These are physical models such as model aircraft or more generally a scaled down replica of a system. There are schematic models that include diagrams, maps and charts. There are symbolic models based on mathematics or computer code. Some models are static and other dynamic. Other distinction concerns

deterministic versus stochastic models. In a deterministic model all entities bear fixed mathematical or logical relationships to each other. In a stochastic model part of the variation is random in nature, hence an investigator, can, at best, obtain average solutions by using stochastic models to solve models.

1.6 INTERACTIVE SIMULATION

In most of the semiautomatic systems human operator is a part of the system. He continuously monitors the system and takes decisions to control the operations ex: air traffic controller on an airfield, manager in an industry, etc. He takes decisions and alters the system state to the desired state. For modelling such a system, the most complex part happens to be the decision process of the human operator. To imitate the human minds capabilities the computational requirements are immense. So it is usually modelled in such a way that all the system is modelled except the human operator. Whenever a human operators decision capabilities are needed the system prompts for interaction.

1.6.1 Design of an Interactive System:

This involves two way communication between computer and the user. Human operator forms the part of the total

system configuration when the simulation is in progress the computer gives various information on system state to the human being, who interprets the information and decides the next course of action. The inputs given by him to the system modify the system state and the new state is conveyed to him once again and this continues.

The potential of interactive simulation is immense as a training aid. It helps to train pilots. These pilots spend much of their training on controls of a flight simulator. This is a mock up of an aircraft flight deck, containing all the usual controls and surrounded by screens on which are projected computer generated views of the terrain visible on take off and landing. The advantages of such simulators are fuel saving, safety, and the ability to familiarize the trainee with a large number of world airports. Similarly the military commander can try out his battle strategy on the simulator before plunging into a battle field.

1.6.2 Computer Graphics:

The best mode of communications is visual, so in interactive simulator, the feedback information is best

provided by visual means [3]. This visual display in the crudest form might contain LEDs or alphanumeric display. On the other end we have display of terrain in aircraft simulator which is quite complex. Interactive computer graphics allow us to achieve much higher band width man-machine communication using judicious combination of text with static and dynamic pictures than is possible with text alone. The higher bandwidth makes a significant difference on an ability to understand data, perceive trends, and visualize real or imaginary objects. By making communications more efficient, graphics makes possible greater productivity, higher quality and more precise results and lower analysis and design costs.

1.6.3 Graphics Programming in Interactive Environment:

A programmer, assumes a graphics package available to him. The program uses facilities provided by the available package. The graphics program creates the three activities.

i) Application model: This stands for a data mass representing the definition of graphic objects.

ii) Description of object view: The object is described for calculation of the desired view and display.

iii) Interactive Handling: The program provides means to convey users interaction to program for specifying modification or changes in the display view.

The first application model involves the basic definition of the objects that the user will manipulate and view. This is a collection of data representing objects and relationships in that data stored in a data structure, e.g., size, shape, placement and attributes like colour, pattern, etc. The second activity creates, transforms and displays the view of the object on the graphics device. This actually might use segment definition and manipulation routines for treating a set of primitives as a single graphic entity. The third activity provides users with interaction by communicating between I/O devices and the program. A variety of input devices are available with graphics packages. Logical classes of devices are five in number.

i) Locator: .to indicate a position and/or orientation.

ii) Pick: to select a displayed entity

iii) Valuator: to input a single value in the space of real numbers.

iv) Keyboard: to input a character string

v) Button: to select from a set of possible alternative actions or choices.

The most common output device is the CRT (colour) terminal for interactive graphics.

1.7 UPDATE DYNAMICS

The easiest way to present a change in view of a graphic object would be to redraw the altered view. In real time graphics application the drawing of complex views will be slow and there will be pauses in between two views. In animation flicker might be observable. This can be obviated by using segment definition and segment transformation routines provided by the graphics package. Once segments are defined they can be rotated, scaled and translated as a single graphics entity. The change of view is quite fast. If even faster change of view is desired, then one can draw all possible variation of views as segments and make them successively visible and invisible to give an effect of smooth motion.

1.8 OVERVIEW OF THESIS

In the next chapter the total air defence system is described with a typical progress of combat. Surface to Air Guided weapons are described in greater detail so that they can be implemented as a sub-model in future. In Chapter 3 the concepts of reliability, model construction and optimisation of an air defence system were carried out. In Chapter 4 the simulation of anti-aircraft guns system is explained with the help of flow charts. In Chapter 5 conclusion and suggestions for future work have been included.

CHAPTER 2

DESCRIPTION OF SYSTEM

2.1 AIR DEFENCE

Of the three arms of the military service available (army, navy and airforce) for the defence of a nation, the airforce is entrusted with the responsibility of safe-guarding the air space on and around the nations territory. For the purpose of air defence the likely targets of the enemy are classified as vulnerable points (VP) and vulnerable areas (VA).

2.1.1 Vulnerable Points and Vulnerable Areas:

Any isolated structure or a building of strategic importance is termed as VP. A typical limit can be say 250m x 250 m in area. Some of the examples of VP are atomic reactor rooms of an atomic power plant, offshore drilling platform, air traffic control tower on an airfield, bridges across rivers, etc. VA is one where the area to be defended is more than VP; ex. two or more VPs situated within a radius of 40 km. This means, VP is an isolated structure of strategic importance within a radius of 40 km. In this context the airfield forms a VA. It consists of various

VPs like air traffic control tower, early warning and surveillance radars, blast pens to house various aircraft, fuel and ammunition dumps, etc. To defend this VA 3 tier system of weapons are usually deployed. The type of weapons are

i) Surface to air guided missiles (SAM)
ii) Anti-aircraft guns (AAG)
iii) Air defence interception aircraft (AD A/C).

Information flow is centered at a place called an air defence control centre for the command and control of these units. A continuous monitoring of the air situation is carried out to evaluate any threat from the enemy aircraft. The information about the aircraft in air is available from various air surveillance radars, adjacent air defence control centres, etc.

2.2 PROGRESS OF COMBAT

In a typical situation early warning about the presence of enemy aircraft will be available at the air defence control centre and the progress of its flight will be continuously monitored. Once it is ascertained that the aircraft is progressing towards the VA the available air defence aircraft at the base are ordered to take off

and are positioned 5 to 10 km from base at a place away from the firing line of SAM and AAG. These airborne aircraft are in standby to chase and destroy the enemy aircraft in the receding mode. When the target aircraft is 40 km away from base, SAM are activated to engage the target. SAM system contains various radars to search, detect and track the intruding aircraft. Once a target enters the killzone of the SAM system, a missile is launched in single or salvo of two depending on the situation and guided towards the target to get a kill. The area of responsibility of SAM is usually till the target aircraft reaches 5 Km from the base. In case of failure of SAM (i.e. when the target has reached a point less than 5 km from the base) the AAG are activated to engage the incoming aircraft. When both SAM and AAG fail to destroy the enemy target the air defence interception aircraft which were already airborne and positioned at a favourable location are told to engage the intruder in the receding mode. Depending on the endurance they chase the target aircraft and fire at them. Once the target is beyond the range or it is destroyed, they come back to base and get ready for the next sortie.

2.3 SURFACE TO AIR MISSILES

A typical combat drill using SAM might progress as described. Depending on the availability of number of missiles the loading of the launchers takes place. This is essential because of restriction of firing missiles in a certain direction. They cannot be fired in the direction of radars because the radars are usually at some height. At a given time in certain directions only two of the three launchers might be available. Enemy target employs various antimissile monoevers and uses different tactics, one being the use of jamming of radars called active jamming. Presence of jammer aircraft must be checked at the earliest so that the type of firing method can be appropriately chosen. When jamming is active the range information will not be available thus missiles may have to be fired in the jammers direction without the range information or partial information from other sources. In normal circumstances the search radar is used to search and detect the presence of enemy aircraft. Once detected it is tracked continuously and various parameters like speed, altitude, range, etc. are ascertained. Once the target enters the kill zone of the SAM appropriate launcher is chosen which is clear of the radar direction. Depending

on the possibility either automatic or semi-automatic tracking is continued. The missile is fired either in single or a salvo of two depending on the availability of the command guidance links for the guidance of missiles in flight. The successful launch of a missile is monitored and it is guided to within 300 m of target. From there an onboard radar will take over and homes on to the target and explosion of the warhead occurs. In case the target is missed the missile goes for self destruction. Further if the target has not come within near boundary of the kill zone relaunch is used and the available missiles in storage are appropriately loaded on the launchers to be ready again for combat.

2.3.1 Specification:

Each SAM unit contains two radars, one for searching and tracking the enemy aircraft, and another for command guidance of the missiles in flight when fired. The beamwidth of the radar in search mode will be larger than in tracking mode for ease in searching the targets. In tracking narrow beam width aids in accurate tracking of target. There are usually 3 to 4 launchers with each having a capacity to launch 4 missiles. These launchers are usually situated at

100 m from the radar all around. A command link to give corrections to the missile in flight depending on the target behaviour is also available. Various information displays like fire control board, which gives the state of launcher and missiles loaded on it, radar scopes for searching, detecting and tracking of aircraft, jamming detectors, parameter displays of aircraft attitude, kill boundaries of missiles in various modes are available.

2.4 HEAD UP DISPLAY (HUD)

Most single pilot military aircraft are now being designed with HUD [4]. The HUD gives the pilot the ability to fly fast at low altitude safely, and improves the tactical effectiveness of the aircraft. Traditionally the approach to flight information displays has been the same in all classes of aircraft. In general two sets of instruments are available on board an aircraft (100% redundency) for all kinds of measurements needed for the air worthiness of the aircraft. A pilot is expected to continuously cross monitor between these two sets of instruments and make judgement in the event of difference (due to mulfunctioning of any set). He will do this by refference to external visual cues, when available, and by correlation between other dependent parameters.

HUD were primarily developed from the electromechanical gun sight to reduce the head-in/head-out scan while performing air to ground weapon aiming tasks. This development was further accelerated by the tactical requirement to performthe high speed low level runs into the area of the target. HUD comprises an optical system, symbol generator and system interface. The pilot sees the projected display through a semi-silvered combiner glass, mounted above coaming level and is able to view a display area measuring about some 20 degrees in azimuth and 15 degrees in elevation without any head movement. The display can be read under almost all the ambient lighting conditions.

CHAPTER 3

MODELLING AND OPTIMISATION

In this chapter we use basic concepts of reliability theory to optimise an air defence system. Further a model is built for combat between bomber aircraft and a battery of AAG.

3.1 DESCRIPTION

For the purpose of air defence airforce consist of various components like

i) Low looking surveillance radars

ii) Medium and high looking radars

iii) Surface to air guided weapons (missiles)

iv) Anti-aircraft guns battery

v) Air defence interception aircraft.

Air defence system can be considered as a series system with five components as given above. In this link every system must function successfully to achieve the objective. The radars give early warning about the intruder enemy aircraft and once the target is in range, missiles are ordered to engage the target from 40 km downwards till it reaches 5 km. At this stage AAG will take over the

combat and try to get a kill. When these also fail, the air defence interceptor aircraft are ordered to chase and destroy the intruder.

Since we have confined our study only to the AAG and bombers, we restrict our attention to the second part as listed above. The combat area for AAG is a radius of 4000 m around the battery of AAG [5]. The enemy bomber carries gravity bombs and flies at a speed ranging from 210 m/s to 300 m/s. The altitude of the aircraft can be upto 1000 m. The pilot has a head up display where the information about the horizontal distance to guns , the target for bomber is available. A bomb released from a bomber will destroy a gun depending on the ranging accuracy of the aircraft radar and the reaction time of the pilot. One can assume the probability of destruction of a gun to be 0.2 if a bomb explodes near it. This probability is independent of the probability of destruction of a neighbouring gun. Usually upto five guns are physically located close together.

When a gun fires a shell at an aircraft, it travels at 1000 m/s. The range information of the bomber is available on a radar screen which is updated at the frequency

of the scan rate of radar. The gunner fires a shell depending on the information available from the radar. Further the radar cross-section area of the aircraft reduces as the distance between the radar and the bomber increases at same altitude. If the shell and the target meet at a distance 'd' from the battery, the aircraft is destroyed with a probability

$$\max (0, 0.3 - d/10000)$$

After firing a shot, reloading of a gun takes finite time which is normally distributed with a mean 5s and standard deviation 0.5s. Before we model the combat let us see some concepts about reliability and optimising techniques used for air defence system.

3.2 RELIABILITY

A measure of how well a system performs or meets its design objectives is provided by the concept of system reliability [6]. In most of the complex systems encountered in practice, it consist of components and subsystems connected in series, parallel or standby, or a combination of these. We will consider a system whose components are assumed to be independent and where operation can be described in discrete forms as either 'operating' or 'failed' over a specified time interval.

3.2.1 Series System:

Systems generally consist of a large number of components connected in series, which means if any one of these fail, the system fails. A system comprising of two components in series is shown in Figure 1.

The reliability of the system with two components in series under basic assumptions of independent component failure and the necessity of successful operation of both

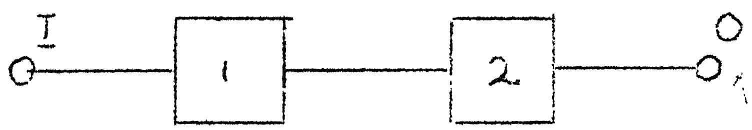


Figure 1: Series system

components is given by

$$R_s = R_1 . R_2$$

and this can be extended to 'n component in series' as

$$R_s = R_1 \; R_2 \; \ldots \; R_n = \prod_{j=1}^{n} R_j$$

where R_j is the reliability of the jth component in series in the system and R_s is the reliability of the total series system.

3.2.2 Parallel System:

Parallel system configuration is often referred to as redundancy. There are two possible paths for the successful operation of the system shown in Figure 2.

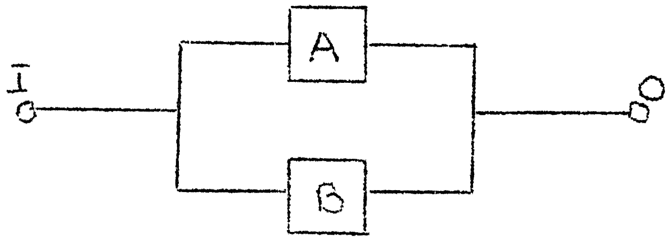


Figure 2: Parallel System

I - A-O or I - B - O

Reliability of parallel system can be found by multiplicative rule of probability. The only way the parallel system can fail is through failure of both the components. Since both the components are assumed to be independent the probability that both fail is the product of their respective unreliabilities. One minus the system unreliability is the reliability of the system

$$R_s = 1-Q_1\,Q_2 = 1-(1-R1)\,(1-R2)$$

and this can be generalised as

$$R_s = 1 - \prod_{j=1}^{n} Q_j$$

$$= 1 - \prod_{j=1}^{n} (1-R_j) \quad \therefore R+Q = 1$$

where Q_j is the unreliability of the jth component.

3.2.3 Series-Parallel System:

The reliability of a system with n components connected in parallel redundancy is

$$R_p = 1-(1-R)^n$$

where R is the reliability of an individual component. If we place n sets in parallel, where each set has m components connected in series, the

$$R_s = 1-(1-R)^n$$

where,

$$R = \prod_{j=1}^{m} r_j \text{ and}$$

r_j is the reliability of jth component in series, thus

$$R_s = 1 - (1 - \prod_{j=1}^{m} r_j)^n$$

The series parallel system configuration is shown in Figure 3.

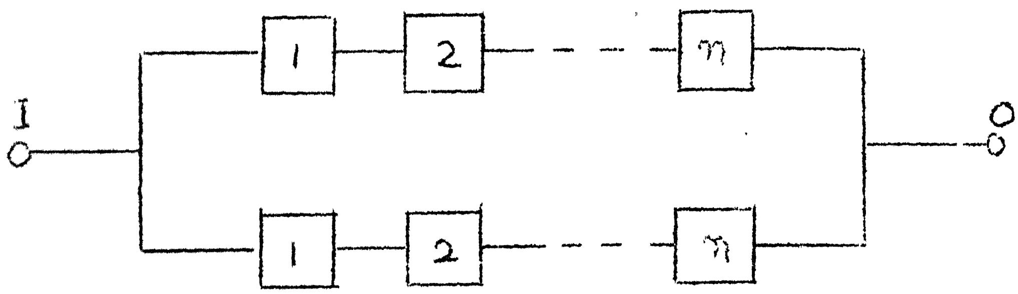


Figure 3: Series Parallel System

3.2.4 Parallel-Series System:

The reliability of n components connected in parallel is given by

$R_p = 1-(1-R)^n$ where R is the reliability of individual component. If m such sets are connected in series, where each set consists of n components in parallel then the reliability of the system is given by

$$R_s = [1-(1-R)^n]^m \qquad (1)$$

The parallel series configuration is depicted in Figure 4.

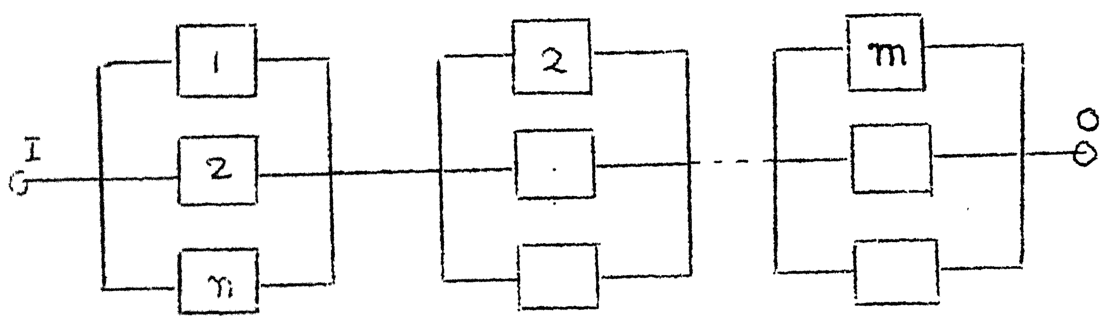


Figure 4: Parallel Series System

3.2.5 Redundancy at Component Level:

Consider the configuration as shown in Figure 5. In this there are n components connected in series, and the set of this n components, is placed in parallel with

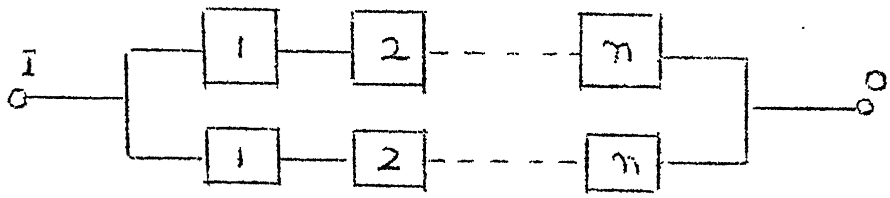


Figure 5: Series Parallel System

another similar set. In configuration of Figure 6 the components have been first placed in parallel, and in turn connected in series.

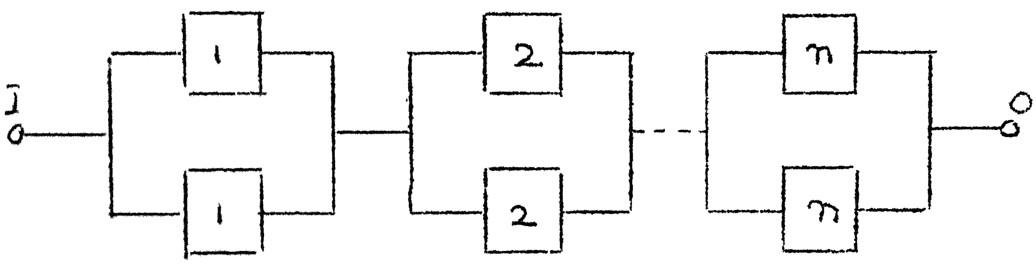


Figure 6: Parallel Series System

Let the reliability of each component be r. The reliability of the system RS1 in first case is expressed as

$$RS1 = 1-(1-r^n)^2$$
$$= r^n(2-r^n)$$

The reliability of the system RS2 in the second case is expressed as

$$RS2 = [1-(1-r)^2]^n$$
$$= r^n\ (2-r)^n$$

The ratio RS2 and RS1 gives

$$\frac{RS2}{RS1} = \frac{r^n(2-r)^n}{r^n(2-r^n)}$$

It is seen that the ratio RS2:RS1 is greater than unity for $r<1$. Hence the configuration of parallel-series system always provides higher reliability. Thus it can be said as components if duplicated in the system at the component level give higher system reliability than if duplicated at the subsystem level. For the optimisation of air defence system the later configuration is used where individual components are paralleled first and integrated into a series system to form a total system.

3.3 MODEL CONSTRUCTION

Here the various submodels of an anti-aircraft guns system are developed to form a combat model.

3.3.1 Model for Bomb Drop:

In the simulation of combat we are interested in finding out the time taken for the bomb to hit the ground from the instance it is released under the force of gravity.

For the sake of simplicity the atmospheric resistance induced on the bomb during the fall was considered to be negligible. The bomb is considered to be a free fall type. It has the forward velocity of the aircraft at the instance of release; that means only force due to gravity is acting on it for the duration of the fall. It is further assumed that there are no 'duds', all bombs explode on impact on the ground. To calculate the time taken for the bomb to reach the ground from the altitude of aircraft the formula

$$S = Ut + \frac{1}{2}at^2 \quad \text{is used,}$$

where S is the distance travelled,

U is the initial velocity,

a is the acceleration and

t is the time taken.

In our case at the time of release, the vertical component of velocity is zero as the altitude of aircraft is assumed to be horizontal at the time of release.

S = altitude of the aircraft and a = 9.81 m/sec^2

we get T = SQRT (2.0*ALTITUDE)/(9.81) where T is the time taken for the bomb to fall to the ground.

In the automode of simulation ideal time to release the bomb to hit the AAG battery is found out. It is given by

$$R\_T = (H\_D/SPD) - T$$

where R_T is the bomb release time,

H_D is the horizontal,distance to guns

SPD is the speed of aircraft at the time of releasing the bomb.

3.3.2 Model for Shell Flight:

Here again the atmospheric resistance on the shell and other forces are neglected. The velocity of the shell is assumed to be constant at 1000 m/s. For the calculation of the impact point the forward speed of the aircraft at the instant of firing is considered constant. In the interactive mode the speed of the aircraft is independently controlled, so after the duration of the flight both aircraft and shell may not meet at a point, then if it is not within a specified distance the shell misses the target.

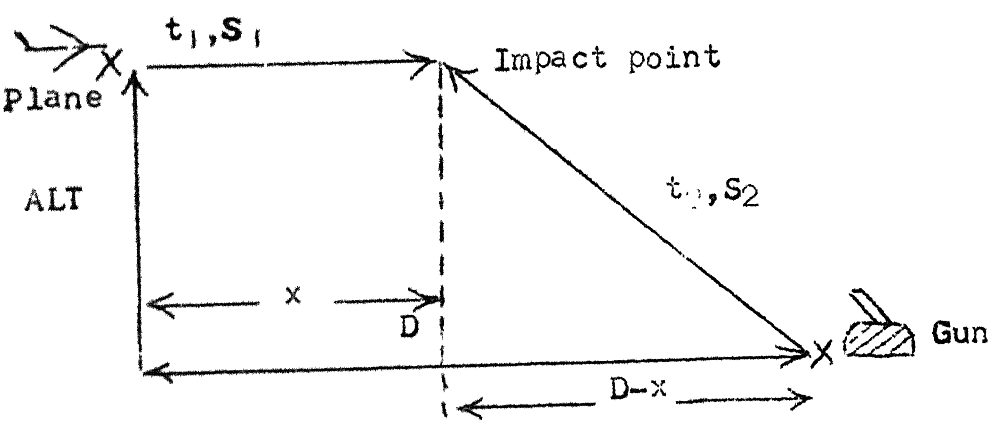


Figure 7: Shell flight

S1 = speed of aircraft

S2 = shell flight velocity

t_1 = time whem aircraft reaches impact point

t_2 = time for shell flight

D = distance to gun battery

ALT= altitude of the aircraft

x = distance travelled by aircraft in time t_1.

$$t_1 = \frac{x}{S1} \qquad t_2 = \text{SQRT }(((ALT)^2 + (D-x)^2)/S2)$$

For both aircraft and shell to meet at a point in space $t_1 = t_2$.

Thus $\frac{x}{S1} = \text{SQRT }((ALT)^2 + (D-x)^2)/S2$

Let S2/S1 = S the speed ratio

$$xS = \text{SQRT }((ALT)^2 + (D-x)^2)$$

i.e. $(S^2-1)x^2 + 2Dx - (ALT^2+D^2) = 0$

thus

$$x = \frac{-(2D+\text{SQRT}(4D^2+4(S^2-1)(ALT^2+D^2)))}{2(S^2-1)}$$

Once x is known it is easy to find t_1 which is equal to t_2 the shell flight time. The same equations are applicable

for both aircraft approaching the battery of AAG and while receding with appropriate sign changes.

3.3.3 Model for Probability of Aircraft Destruction:

The gunner a human operator sitting at the console of a radar has the picture of the air situation on the scope. He has got a finite reaction time. The radar picture is updated in step with the scan frequency. Further the radar cross-section of the bomber keeps on reducing as the range increases. Thus the probability of destruction of aircraft is inversely proportional to the distance between aircraft and gun. The closing speed of shell and an aircraft differs for approaching and departing aircraft. If the shell and its target meet at a distance d from the battery, the aircraft is destroyed with a probability max (0,0.3-d/10000). If we measure distances from the battery in the direction of travel of the aircraft, Figure 8 shows the probability of hitting a target as a function of its distance away at

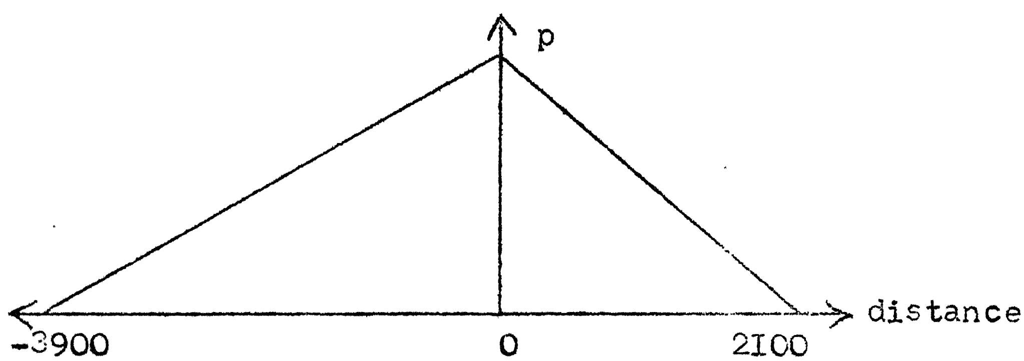


Figure 8: Hit probability as a function of range

the time of firing. Here it is drawr for a typical case where speed of aircraft is 300 m/s and shell travels at 1000 m/s.

3.4 RANDOM NUMBERS

In the stochastic modelling of a system,generation of random numbers uniformly distributed in a specified interval is fundamental. The probability of aircraft destruction, gun damage, etc.are random in nature. The system pseudorandom number gives uniformly distributed random numbers between 0 and 1. To obtain a normal distribution they have to be transformed. To get three different series of random numbers from the system pseudo random number generator three seeds are specified during the initialisation of the program. In a particular series of random numbers the first call to random number uses the specified seed and the next seed value for the subsequent calls is calculated using the formule.

SEED = 69069 * SEED+1 (MOD 2**32)

For modelling the reload time of a gun, it takes a finite time and this time is not constant but varies from crew to crew and other factors. Normal distribution is assumed for the reloading of the gun. To generate this a transformation

is applied to the uniform variable. Although there is no closed form expression F^{-1} ODEH and EVANS (1974) gave the following approximation [5] of $X = F^{-1}(U)$ for standard normal. U is uniform variable

$$X = Y + \frac{p_0+p_1y+p_2y^2+p_3y^3+p_4y^4}{q_0+q_1y+q_2y^2+q_3y^3+q_4y^4}$$

where y = SQRT (-LOG([1-U]^2))

and $p_0 = -0.322232431088$ $q_0 = 0.099348462606$

$p_1 = -1$ $q_1 = 0.588581570495$

$p_2 = -0.3422242088547$ $q_2 = 0.531103462366$

$p_3 = -0.0204231210245$ $q_3 = 0.10353775285$

$p_4 = -0.0000453642210148$ $q_4 = 0.0038560700634$

This approximation has a relative accuracy of six decimal places and is valid for $0.5<U<1$ by the transformation $U = 1-U$ and $X = -x$. We can extend it to $0<U<1$.

3.5 OPTIMISATION

There are various methods of improving the reliability of a system. Redundancy is the only effective method in system planning stage [7]. As seen earlier the air defence system can be considered as a series system with five stages with x_j redundant components at stage j from the equation (1) it is easily seen that [8]

$$Q_S = 1 - \prod_{j=1}^{N} (1-Q_j^{x_j})$$

$$\sum_{j=1}^{N} Q_j^{x_j} \qquad (2)$$

subject to

$$\sum_{j=1}^{N} q_{ij} (x_j) \leq b_i \quad i=1,2,\ldots \qquad (3)$$

where,

Q_j = unreliability of one component at jth stage

Q_S = system unreliability

$q_{ij}(x_j)$ is resource i consumed in stage j, and

b_i is the available resources.

To reach Q_s in successive steps add one redundant component to the stage with higher $Q_i^{x_j}$ in Equation (2). If constraint in Equation (3) are not violated. The steps involved in solving the problem are

1) Assign $x_j=1$ for $j=1,2,\ldots$ N because this is a cascade system
2) Find the stage which is the most unreliable, add a redundant component to this stage.

3) Check the constraints

   a) if any constraint is violated, go to (4)

   b) if no constraint has been violated go to (2)

   c) if any constraint is exactly satisfied stop. The current x_js are optimum.

4) Remove the redundant component added in 2. The resulting number is the optimum allocation for stage. Remove this stage from further consideration.

5) If all stages are removed from consideration, the current x_js are the optimum configuration of the system, otherwise go to (2).

With the algorithm outlined above a typical air defence system is optimised as shown in Tables 1 and 2. The reliability factors for various stages is given in second row of Table 1 with cost and weightage factors in successive rows. These factors are normalised in the scale 1 to 10. Maximum constraints are cost $\leq$ 132 and weightage $\leq$ 143 for the purpose of optimisation. At the end it is realised from Table 2 that the reliability of the total system comes out to be 98.495%.

Table 1: Parameters

	AAM	AAGUNS	AD A/C	RADAR I	RADAR 2
Stage	1	2	3	4	5
Reliability	0.9	0.65	0.8	0.75	0.85
Cost	9	5	8	4	7
Weightage	8	7	9	6	8

Cost $\leq$ 132

ωt $\leq$ 143

Table 2: 'Optimization

Number of elements					Unreliability of stages						
n_1	n_2	n_3	n_4	n_5	1	2	3	4	5	Total cost	Total ωt
1	1	1	1	1	.1	.35[a]	.2	.25	.15	33	38
1	2	1	1	1	.1	.1225	.2	.25[a]	.15	38	45
1	2	1	2	1	.1	.1225	.2[a]	.0625	.15	42	51
1	2	2	2	1	.1	.1225	.04	.0625	.15[a]	50	60
1	2	2	2	2	.1	.1225[a]	.04	.0625	.0225	57	68
1	3	2	2	2	.1[a]	.0428	.04	.0625	.0225	62	75
2	3	2	2	2	.01	.0428	.04	.0625[a]	.0225	71	83
2	3	2	3	2	.01	.0428[a]	.04	.0156	.0225	75	89
2	4	2	3	2	.01	.0150	0.4[a]	.0156	.0225	80	96
2	4	3	3	2	.01	.0150	.008	.0156	.0225[a]	88	105
2	4	3	3	3	.01	.0150	.008	.0156[a]	.0033	95	113
2	4	3	4	3	.01	.0150[a]	.008	.0039	.0033	99	119
2	5	3	4	3	.01[a]	.0052	.008	.0039	.0033	104	126
3	5	3	4	3	.001	.0052	.008[a]	.0039	.0033	113	134
3	5	4	4	3	.001	.0052	.0016	.0039	.0033	121	143
Reliability					.999	.9947	.9984	.9960	.9966		

TOTAL RELIABILITY OF SYSTEM = 0.9849523

a: most unreliable stage

CHAPTER 4

SIMULATION OF THE SYSTEM

In this chapter we describe the simulation procedure evolved to carry out the study. The procedure includes:

a) Description of the simulation run

b) Specification

c) Flow chart of the program

d) Other details

4.1 SIMULATION RUN

The program is run in two, distinct phases

i) Automatic mode

ii) Interactive mode

In the automatic mode a maximum of 5 aircrafts and a battery of 5 guns can take part in the combat. The program-run begins with initialisation of the parameters like number of aircraft, their speed, altitude and the number of guns in the battery. Once the initial parameters are set the program generates various graphic segments and displays on the screen the views. It schedules the game begin and game end events. The next event is brought forward and system time is accordingly increased. During the event execution various other events

are further generated and these are pushed into the queue to form a new schedule. At every step the display on the screen is appropriately modified. The simulation terminates if any one of the following events take place.

a) All the aircraft are shot down

b) All the guns are destroyed

c) All the events scheduled are over

d) Time limit is exeeeded.

The results of the simulation run are computed and are displayed as a message on the screen.

In the interactive mode there is only one aircraft and the battery of guns may contain a maximum of 5. Here at every step the program prompts the player to respond with appropriate answers for the progress of the game. The answers are validated and the game progresses till any one of the three events occur like aircraft shot down, guns destroyed or time limit crossed. Here the display is different. The cockpit view of combat is in the form of a head up display. The radar picture is available for the battery of guns with individual control of the guns independently.

4.2 SPECIFICATIONS:

4.2.1 Combat:

Combat area of the anti-aircraft guns is restricted to a radius of 4000m around the battery of guns in both automode and interactive mode. Simulation run is terminated and results displayed if any one of the following three events take place.

i) All the aircraft are shot down
ii) All the guns are destroyed
iii) Time limit set is exceeded

4.2.2 Bomber:

Number of aircraft	= 1 to 5
Minimum speed	= 210 m/s
Maximum speed	= 300 m/s
Minimum altitude	= 100 m
Maximum altitude	= 1000 m
Armament carried	= Bombs

4.2.3 Guns:

Number of guns	= 1 to 5
Shell flight speed	= 1000 m/s
Effective range	= 4000 m

In the simplistic model it is assumed that the change of parameters of aircraft are in steps like speed change is in multiples of 10. Once bombs are dropped they are assumed to be of free fall type. Similarly the air resistance and gravity effects on the flight of shell fired from gun are ignored. Once the bomb bursts near the battery of guns the guns are destroyed independently of each other.

4.3 FLOW CHART

The detailed flow chart of the program is given in Fig. 9. In the automode six different events can happen during simulation.

i) arrival of an aircraft within range,

ii) an aircraft flying over the battery of guns releasing bomb,

iii) the released bomb exploding near battery,

iv) a gun finishing reloading,

v) the shell fired bursting near aircraft, and

vi) end of simulation.

Arbitarary integer codes were given to these events. The array PLANOK tells us whether a plane is in range and still flying. The arrays GUNOK and GUNRDY tell us

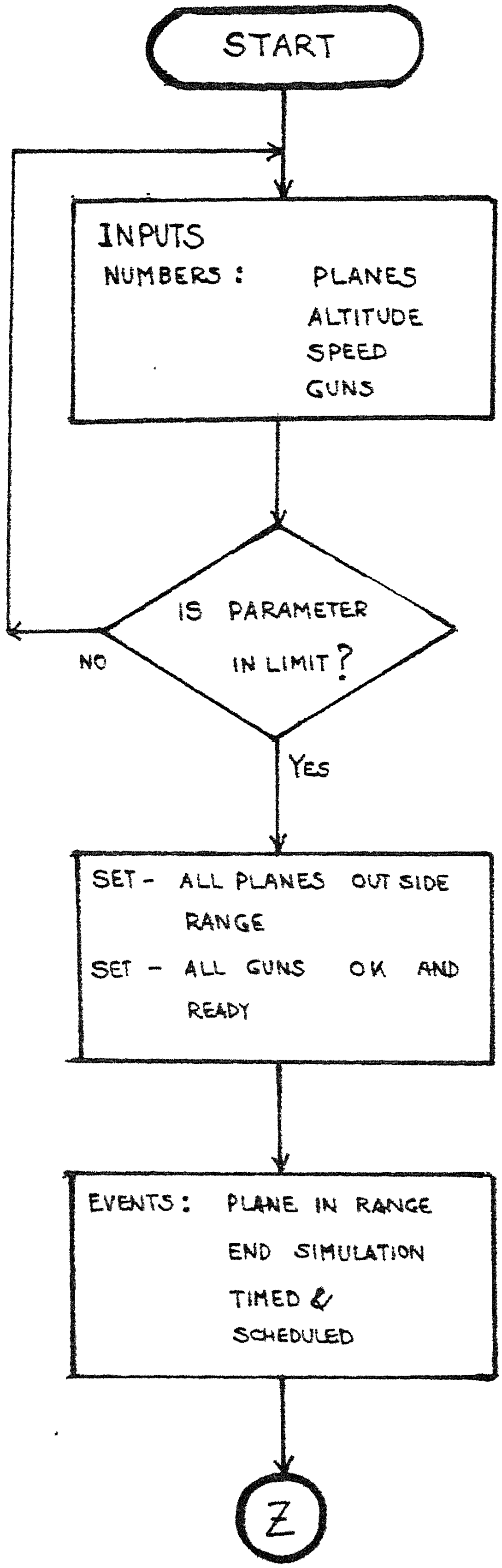
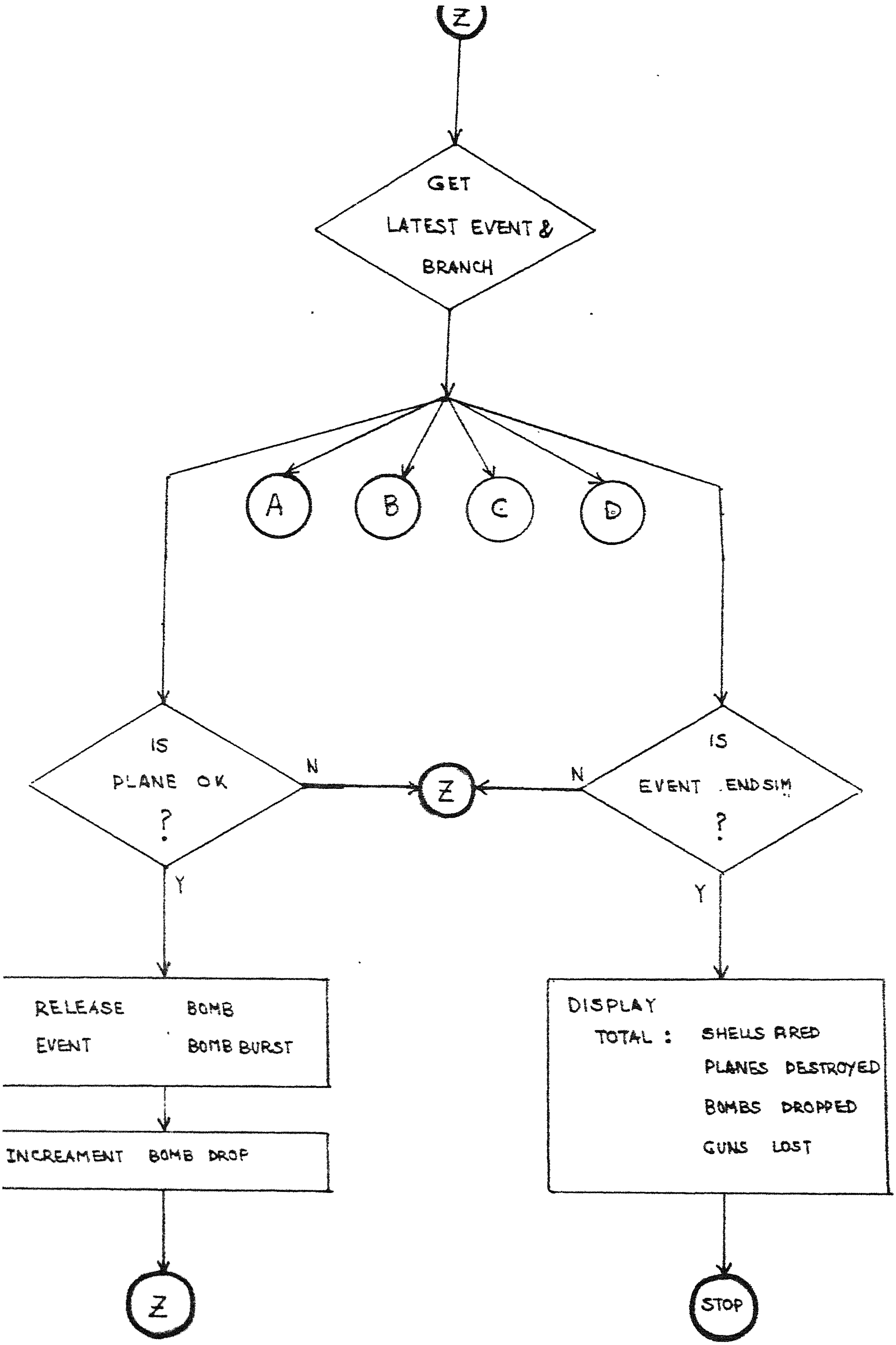
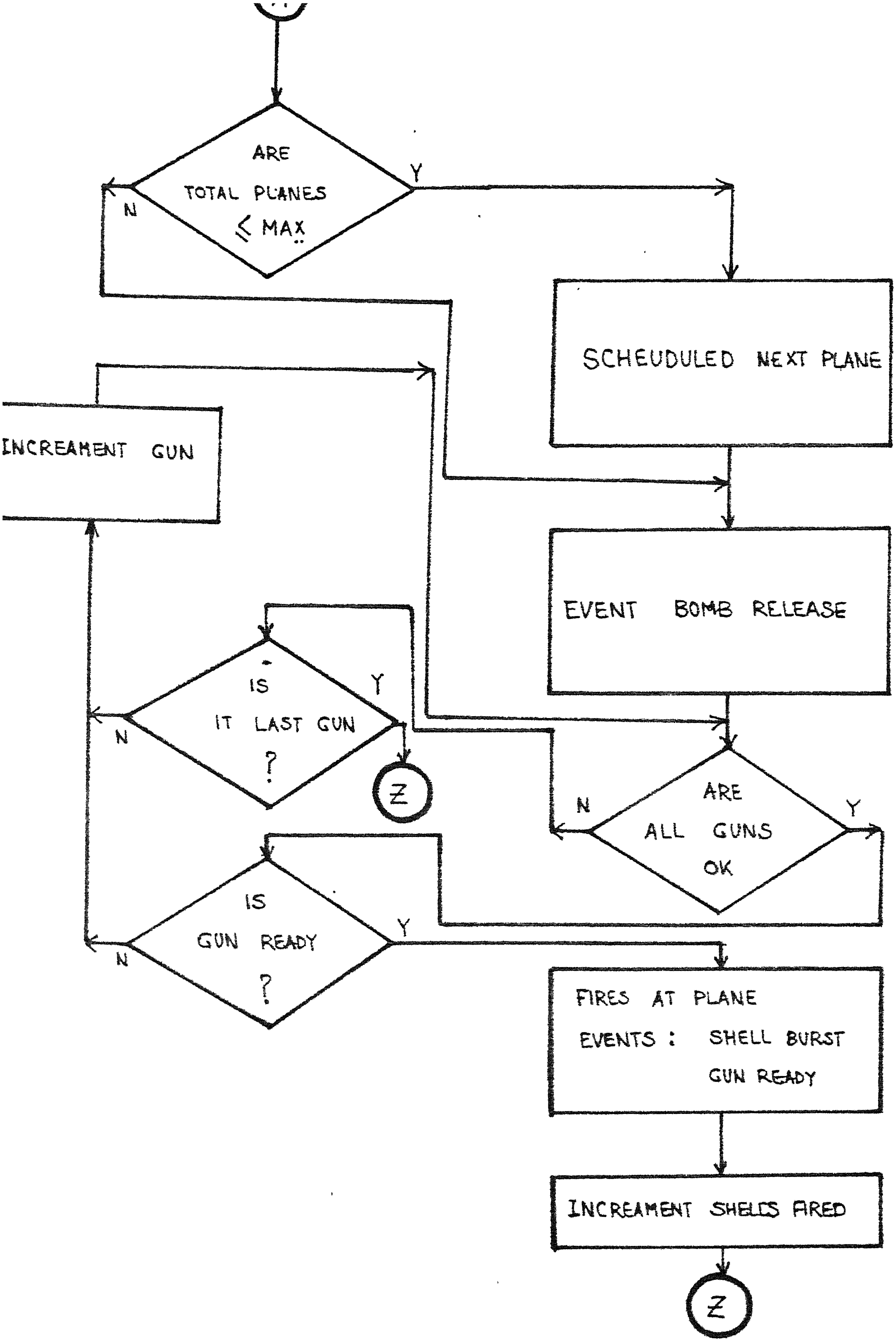


FIGURE 9a FLOW CHART



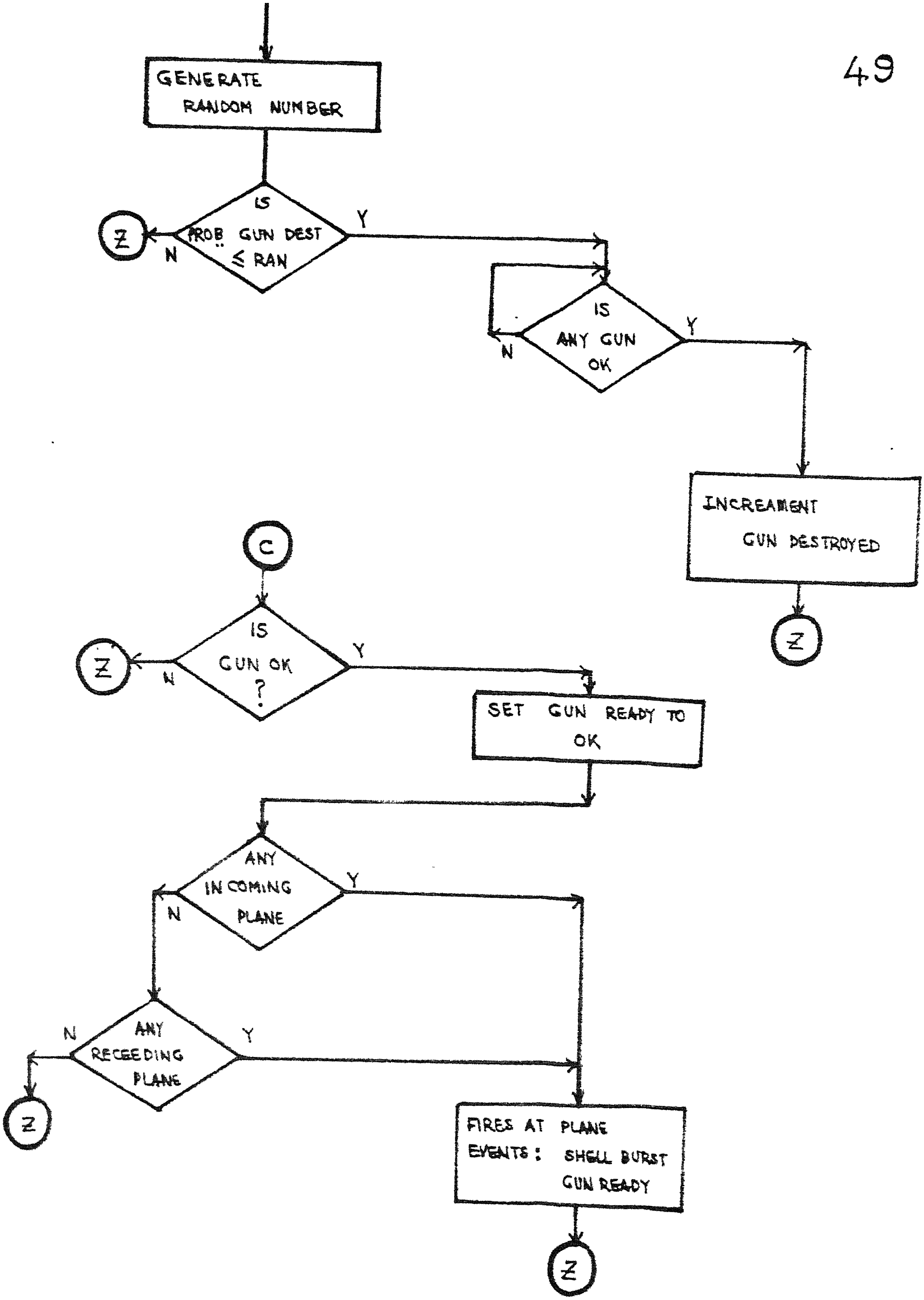
Z
GET
LATEST EVENT &
BRANCH
A
B
C
D
IS
PLANE OK
?
N
Z
N
IS
EVENT .ENDSIM
?
Y
Y
RELEASE BOMB
EVENT BOMB BURST
INCREAMENT BOMB DROP
DISPLAY
TOTAL : SHELLS FIRED
PLANES DESTROYED
BOMBS DROPPED
GUNS LOST
Z
STOP

Figure 9b



ARE
TOTAL PLANES
≤ MAX
Y
N
SCHEUDULED NEXT PLANE
INCREAMENT GUN
EVENT BOMB RELEASE
IS
IT LAST GUN
?
Y
N
Z
ARE
ALL GUNS
OK
N
Y
IS
GUN READY
?
Y
N
FIRES AT PLANE
EVENTS : SHELL BURST
GUN READY
INCREAMENT SHELLS FIRED
Z

FIGURE 9c


GENERATE RANDOM NUMBER
IS PROB GUN DEST ≤ RAN
Y
N
Z
IS ANY GUN OK
Y
N
INCREAMENT GUN DESTROYED
Z
C
IS GUN OK ?
Y
N
Z
SET GUN READY TO OK
ANY INCOMING PLANE
Y
N
ANY RECEEDING PLANE
Y
N
Z
FIRES AT PLANE
EVENTS : SHELL BURST
GUN READY
Z

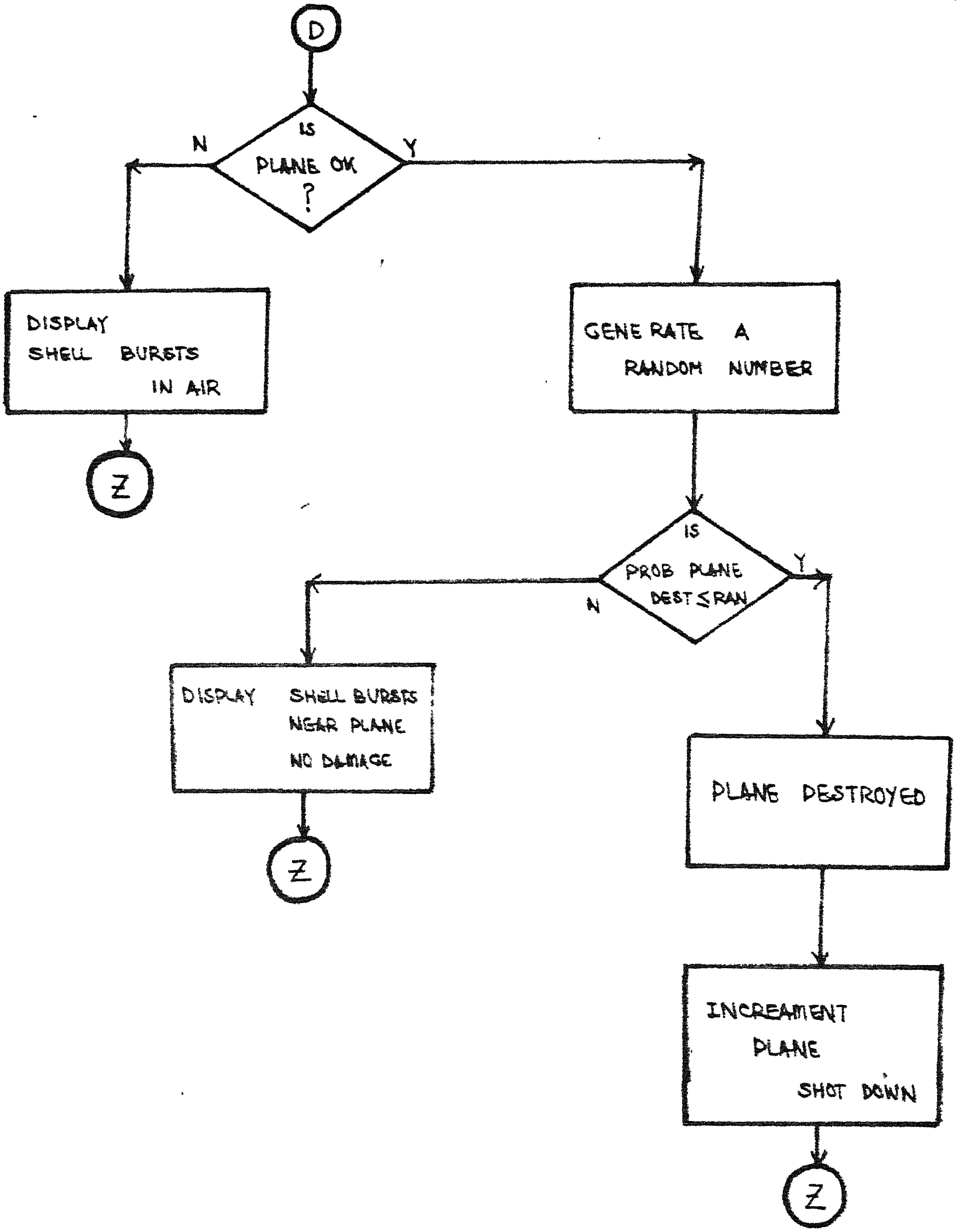

D
IS PLANE OK ?
N
Y
DISPLAY SHELL BURSTS IN AIR
Z
GENERATE A RANDOM NUMBER
IS PROB PLANE DEST ≤ RAN
N
Y
DISPLAY SHELL BURSTS NEAR PLANE NO DAMAGE
Z
PLANE DESTROYED
INCREAMENT PLANE SHOT DOWN
Z

Figure 9a

respectively whether a gun is still in action and whether it is ready to fire. Two scheduling routines PUT and GET are used with TIME as a common block.

Schedule is initialised by inserting an event to represent the arrival of an aircraft 1 at the firing line, and another event to end the simulation. Each arriving aircraft causes its successer to be scheduled, in this way the schedule is kept short. The main loop of the program consists of extracting the next event from the schedule using GET (which also advances the TIME) and branching to appropriate code to simulate the effects of this event.

The scheduled events are not cancelled. If a gun is destroyed while it is getting reloaded, the corresponding READY event still occurs, but it is tested at the start whether the gun is still in action when it branches to this event.

In the interactive mode the only difference is that there is only one aircraft and it carries 10 bombs to be dropped independently. Here the program continuously prompts the user for response regarding the state of the game and the end result is computed.

4.4 OTHER DETAILS

This simulation is implemented on a NORSK DATA 560/CXA computer in ND superset of FORTRAN-77 using PLOT-10 GKS graphics package to give graphics presentation on a TEKTRONIX-4109A terminal. The program execution is on SINTRAN-III operating system. The techniques adopted for specific program modules implementation are described.

4.4.1 Graphics Routines:

The view on screen are generated by making calls to PLOT-10 GKS library routines and set up commands of TEK-4109 terminal. The changes of view is effected by initially storing all possible representations of various states as invisible segments and then making them selectively visible to represent the instantaneous variable values. ND PLOT-10 GKS manual [9] gives description of graphics environment routines, primitive routines, attribute setting routines etc. as provided by ND PLOT-10 GKS implementation. In the interactive mode the aircraft blip on the radar screen is continuously transformed from point to point to represent animation.

4.4.2 Inputs:

The interactive input is monitored by scanning the key board buffer at every prompt cycle. Key board buffer is flushed after each read operation. Sintran-III reference manual [10] describes the input output operations.

4.4.3 Computation Routines:

These routines operate on data and interactive values to calculate the consequent system state. These routines use FORTRAN-77 as described in ND FORTRAN manual [11].

CHAPTER V

CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

6.1 CONCLUSION

We have developed software for interactive simulation of a simplified air defence system. We show the combat between a bomber aircraft and AAG battery. This was developed in two phases one an automatic mode and another interactive mode. Due to limited resources during the course work it was possible to develop the package only to a limited level of sophistication. Systems simulated were assumed to be simple. In actual practice, the air defence system would involve more parameters including various radars, missiles, aircraft and other effects. Therefore, the software developed for such a system will be an extention of our work.

In the graphics part various GKS library routines were used to generate and manipulate various views using segments [11]. Here there was a mismatch between the speed of the program execution and graphics display. It was not acceptable. This problem was solved by using the set up commands of the Tektronix terminal for manipulation of [12] segments. The response time had dramatically improved and

the program execution and graphics view manipulation were in synchronism. The user feedback warning messages are implemented to a limited extent. The program is implemented in ND Fortran-77 and with minor modifications it is portable.

5.2 SUGGESTION FOR FUTURE WORK

This simulation could be used as a starting model for a more sophisticated air defence model.

i) The aircraft parameter control model can be expanded to include various manoeuvers.

ii) The damage assessment could be expanded to include various attitudes of aircraft and gun positions in the AAG battery.

iii) When guns are located closely they are not destroyed independently but are dependent on neighbouring guns. So this factor could be incorporated.

iv) To develop a total air defence model various submodels have to be included like SAM, air defence interception air craft, radars, etc.

v) The specifications of SAM are included in this work. This can be developed as a submodel and integrated into a total system.

vi) To make the model more realistic the interaction of meteriological conditions and terrain features on performance of weapon system can be included.

vii) Inclusion of some factors to cater for intangibles like leadership, morale, training, technology, etc. makes it more realistic.

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